Articles

Restaurant Noise, Hearing Loss, and Hearing Aids

CHARLES P. LEBO, MD; MANSFIELD F. W. SMITH, MD; ELLEN R. MOSHER, MS, *San Jose;*
SUSAN J. JELONEK, MBA, *Fairfield;* DAVID R. SCHWIND; KAREN E. DECKER;
HARLAN J. KRUSEMARK; *and* PAMELA L. KURZ, *San Francisco, California*

Our multidisciplinary team obtained noise data in 27 San Francisco Bay Area restaurants. These data included typical minimum, peak, and average sound pressure levels; digital tape recordings; subjective noise ratings; and on-site unaided and aided speech discrimination tests. We report the details and implications of these noise measurements and provide basic information on selecting hearing aids and suggestions for coping with restaurant noise.

(Lebo CP, Smith MFW, Mosher ER, et al: Restaurant noise, hearing loss, and hearing aids. West J Med 1994; 161:45-49)

Restaurants are not merely eating and drinking sites; they are also popular settings for important social and business conversations. For the more than 27 million Americans with impaired hearing, restaurant noise can be debilitating. Hearing loss is ranked fourth among chronic medical conditions affecting Americans aged 65 and older. More than 3 million Americans wear hearing aids. Hearing impairment affects one in ten Americans. By age 50, 20% of Americans have a hearing loss.[1,2]

Existing disability statutes in the United States do not yet require noise control in restaurants, but it has been reported that the US Department of Justice, under the Americans With Disabilities Act of 1990, has taken the position that compliance with this legislation entails providing quiet listening areas in restaurants and other places in which hearing-impaired persons may convene. A report on this subject by the US Department of Justice is scheduled for early release.

Although persons with normal hearing do experience hearing difficulties in restaurants, the inability to understand speech in noisy restaurants may be a symptom of undiagnosed hearing loss. Poor speech discrimination in social groupings or in restaurants can become so frustrating that many otherwise active and healthy hearing-impaired adults tend to avoid outside dining and social activities.

Several years ago, two of us (E.R.M. and S.J.J.) initiated the use of a questionnaire for hearing-impaired adults to identify difficult listening environments and important listening situations ("Patient Satisfaction Survey," unpublished data, February 1993).[3] The results of this ongoing survey indicate that more than 80% of this group is dissatisfied with its ability to hear and understand conversation in restaurants, both with and without hearing aids. Restaurants are also listed as one of the four most important listening situations by more than 60% of those surveyed.

The most common type of acquired hearing impairment is sensorineural hearing loss, the principal causes of which are aging and noise-induced inner ear damage. Persons so affected hear better in quiet settings than in noisy ones. To address patients' speech intelligibility requirements in noise, audiologic procedures were modified to include quantitative measurements of unaided and aided sound-field speech discrimination in varied noise conditions with different speech stimuli and "real-ear" measurements (taken with a probe microphone placed in the external auditory canal). These test data were integrated into decisions regarding hearing aid selection and earmold configurations. Evaluation of an extensive patient database revealed that speech discrimination problems in noise are not adequately ameliorated by the types of hearing aids most commonly provided for them: linear circuitry and an in-the-ear or in-the-canal configuration. Currently, such hearing aids are routinely dispensed without testing their performance in background noise.

The US Food and Drug Administration has recently charged six major hearing aid companies with excessive or unsubstantiated advertising claims regarding the extent to which their products help users hear amid noise ("Technology and Health," *Wall Street Journal,* April 27, 1993, p 6; Associated Press (on-line), April 26, 1993, 1629 EDT, V0122).[4] Restaurants, sports events, and theaters were mentioned as areas where hearing aids do not perform in accordance with advertising claims.

Objectives

This study was designed to measure specific noise and

From the Hearing Institute for Children and Adults Medical Group, San Jose (Drs Lebo and Smith and Ms Mosher); Microsound Products, Fairfield (Ms Jelonek); and Charles M. Salter and Associates (Mr Schwind and Ms Decker), and Reid and Tarics Associates (Mr Krusemark and Ms Kurz), San Francisco, California.
Reprint requests to Hearing Institute for Children and Adults, 2120 Forest Ave, San Jose, CA 95128.

relevant interior design features in restaurants of various types, evaluate hearing-aid performance in the presence of restaurant noise, and make digital tape and compact disc recordings of restaurant noise for clinical use.

Patients and Methods

A multidisciplinary research team consisting of two otologists, one audiologist, two architects, two acoustical engineers, and one communication scientist was assembled. We selected 27 San Francisco Bay Area restaurants to include all major restaurant types. A multiparametric measurement protocol was developed to describe the acoustic characteristics of restaurants.

Restaurant acoustic evaluations, sound pressure level measurements, subjective noise evaluations, digital tape recordings, and both aided and unaided speech discrimination tests were conducted by this team during peak eating times (with management consent) on Friday and Saturday nights. In addition to the calibrated measuring and recording hardware used by our acoustical engineers, an inexpensive type 3 sound-level meter (calibrated before use) was used for comparable measurements (decibels on the A and C slow scale) by another member of the team.

The measurements included A- and C-weighted maximum, minimum, and integrated (average) noise in various areas of each restaurant. The minimum noise sampling time was five continuous minutes. Each team member subjectively rated the intensity of restaurant noise using a scaled evaluation form. All measurements, observations, and tests were conducted almost simultaneously. Data were either recorded on site and saved by computerized measuring equipment or entered into a portable computer database immediately after exiting each restaurant.

A male subject with age-related hearing loss (it was not feasible to bring a statistically representative group of hearing-impaired subjects into these restaurants) was used to evaluate the performance of certain hearing aids in restaurants. This subject was fitted binaurally with behind-the-ear hearing aids equipped with both linear and nonlinear, multiband compression circuitry. A user-operated switch controlled the type of amplification in use. Aided and unaided speech discrimination testing was conducted in each restaurant, using a supplemented Harvey Gardner three- to four-syllable high-frequency word list.[5,6] Two subjects with normal hearing were used periodically to establish speech discrimination baselines.

The single-subject on-site evaluation of hearing aid performance in restaurant noise was expanded with more extensive sound-booth studies and real-ear measurements involving 57 subjects, using the same nonlinear, multiband compression, behind-the-ear hearing aids, standard noise tapes, restaurant noise recordings on compact discs, and other audio material recorded during the restaurant visits.

Spectral analyses of digital audio recordings and real-ear measurements of the hearing aids used were completed later using a FONIX 6500 (Frye Electronics) test set.

Results

This study generated a massive amount of multiparametric data. Because this article focuses on otologic and audiologic aspects of those measurements, only data germane to these concerns are included.

Noise Profiles of Restaurants

The range of A-scale-decibel (dBA) sound-pressure levels in our restaurant samples was wide. The average loudness ranged from 59 to 80 dBA sound-pressure levels (Table 1). The mean loudness level in all restaurants surveyed was 71 dBA sound-pressure levels, and the median was 72 dBA sound-pressure levels.

The average loudness level of 71 dBA sound-pressure levels is particularly important because it exceeds the average intensity of conversational speech (65 dB). Because speech intelligibility varies directly with the signal-to-noise ratio, the latter measurement is useful in evaluating the suitability of these restaurants for personal communication. Speech intelligibility requires a signal-to-noise ratio of +6 for persons with normal hearing and +12 for persons whose hearing is impaired.[7]

We classified the evaluated restaurants in terms of average noise level and signal-to-noise ratios as follows:

- *Type 1.* Less than 65 dBA; signal-to-noise ratio = 0: 6 restaurants. Quiet atmosphere with (designed or unplanned) acoustical serenity.
- *Type 2.* 65 to 74 dBA; signal-to-noise ratio = ≤10: 15 restaurants. High variability of speech intelligibility in both normal and hearing-impaired subjects.
- *Type 3.* 75 or more dBA; signal-to-noise ratio = >10: 6 restaurants. High ambient noise levels with or without music; conversation difficult for patrons with normal hearing and poor to impossible for persons with hearing losses.

Noise crested (peaked) as high as 87 dBA in some of the restaurants studied. It is important to note that the crest factor (the peak sound-pressure level minus the root-mean-square sound-pressure level during a stated time period) in restaurant noise is as critical as the average sound-pressure level because these noise peaks disrupt the ability of a listener to concentrate and to process speech effectively.[8] High crest factors tend to overload hearing aid amplifiers, with resultant signal distortion. They tend to cancel key speech consonant sounds, there-

TABLE 1.—*Ranges of Background Noise Levels in Restaurants Included in This Study*

Restaurant Types	*Decibels (dB) on the A Scale*
Bistro	65-80
California cuisine	74-80
Elegant	60-66
Ethnic	70-76
Family	59-70
Fast food	75-77
Steak	66-70

by reducing speech intelligibility. Restaurants with dramatically fluctuating noise levels present serious difficulties for patrons whose hearing aids require manual (local or remote) volume adjustments.

Independent Subjective Noise Evaluations

To establish how accurately diners might appraise loudness levels without the benefit of electronic measuring equipment, each member of the team rated each restaurant for loudness, using a five-point scale. These subjective appraisals correlated well with electronic acoustic measurements ($r = .88$).

Noise and Restaurant Types

Although the Zagat restaurant surveys list 32 restaurant types,[9] we deemed seven classifications to be adequate for our purposes: bistro, California cuisine, elegant, ethnic, family, fast food, and steak.

We found that restaurant classifications do not reliably predict loudness levels (Table 1). Elegant restaurants tended to be quiet, and bistros tended to be noisy, but there were exceptions. Such classifications, ours included, do not generally include ambient noise levels in their definitions. We found no correlation between price or food ratings and noise levels.

Acoustic and Architectural Design Factors

Restaurant profiles were compiled using the following variables: location (street type and traffic), building site access (distance to street, proximity to parking), occupancy (maximum seating, percentage of occupancy, actual numerical occupancy), environment (dining, reception, and bar areas, music and ancillary rooms) and dining room configuration (size, volume, walls, percentage of glass, ceiling material and height, flooring material, chair and table type and covering, booth type and covering). Although certain materials and architectural design features help control ambient noise, it is difficult to predict the interior ambient noise conditions accurately by means of these architectural features alone ("Best Meals, Best Deals," *Consumer Reports* 1992; 57:356-372).

Hearing Aid Performance

Our hearing-impaired subject (moderately severe, binaural, high-frequency hearing losses) was tested in all studied restaurants with Audiotone MSP-90C (Bausch & Lomb) behind-the-ear hearing aids, which are equipped with a switch that permits the user to select either the linear or the multiband compression circuitry. These aids were fitted with special nonoccluding Micro Ear ear molds, which are fabricated from Polysheer II, a polymerized vinyl compound made specifically for Pacific Coast Laboratory, San Leandro, California. These open ear molds have long, thin-walled ear canal tubes (usually 4 mm in external diameter) to avoid feedback (Figure 1). They permit the entry of nonamplified low-frequency sound into the ear canal in a normal manner and free the wearer from occlusion effects (the sensations caused by

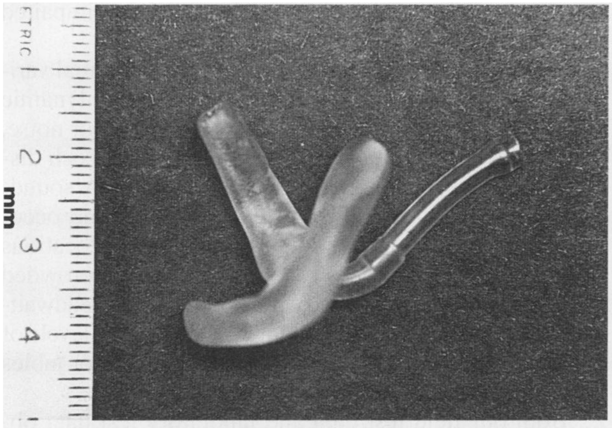

Figure 1.—A typical Micro Ear behind-the-ear ear mold is shown. Note the length of the ear canal tube.

occluding the external auditory canal), including amplification of the user's voice by a hearing aid, foreign body awareness, acoustic effects, and attenuation. Amplification of the user's voice by hearing aids causes the user to reduce, rather than increase, vocal loudness in noise, causing hearing problems for the user's companions.[2,10,11]

The three- to four-syllable high-frequency words described previously were presented by the same speaker to the hearing-impaired subject to assess speech discrimination unaided and using both linear and multiband compression amplification. To evaluate the communication difficulties further, two team members with normal hearing also underwent the speech discrimination tests under identical conditions (in 11 restaurants only). The hearing-impaired subject's aided and unaided performances were compared in 11 restaurants. Surprisingly, the subject's unaided discrimination scores were higher than aided scores with linear amplification in 9 (45%) and equal in 1 (9%) of the studied restaurants. Unaided scores were never higher than those obtained when multiband compression amplification was used.

The performance of the multiband compression mode in the restaurant environment was substantially better than that obtained with linear amplification. The linear scores were poorer than those recorded with multiband compression in 18 of 27 restaurants (67%), equal to the multiband compression scores in 9 of the latter (33%), and better in none.

Discussion

The ambient noise levels in the restaurants studied varied greatly. There was an 18-dBA range in average loudness among the restaurants studied. Noise levels variably interfered with conversation, ranging from no interference to almost total masking. Speech discrimination testing of subjects with normal hearing and one hearing-impaired person indicated these masking effects can confound persons with normal hearing as well as those with impaired hearing. The critical background noise level for speech discrimination occurs between 65 and 70 dBA and corresponds with a signal-to-noise ratio of 0 dB.[12,13] When background noise levels exceed this level, it becomes increasingly difficult for both normal and hearing-impaired persons to communicate.[14]

Our restaurant measurements showed substantial variability in loudness characterized by continual dynamic shifts that, whether caused by music, voices, floor noise, food service, or combinations thereof, erode speech discrimination. Within a given restaurant, the dBA sound-pressure level can vary with seating location and occupancy level; communication is easier in certain locations and is enhanced by low occupancy. Small, crowded rooms, however, can intensify noise levels. The headwaiters (or seating hosts) we encountered had mixed levels of awareness of the locations of the quietest areas or tables in their establishments.

Both our field test data and laboratory test data obtained with our restaurant recordings indicate environmentally that, for speech discrimination in restaurant noise, linear amplification is inferior to nonlinear amplification combined with adaptive multiband compression. This conclusion is supported by the aforementioned 57-subject study, which used the same hearing aid technology and employed both sound field and real-ear measurements of aided performance in noise.[3]

We encountered differences in hearing aid and subjects' performance with changes in background noise levels. The compression spectrum of the hearing aid (and the functional limitations thereof) and the specific settings of the circuitry are critical to any person's aided performance in noise. Ear-mold configuration is another variable that can greatly affect performance in noise. For the single subject in this study, some of the aided discrimination scores recorded in the noisiest establishments were better than others obtained in less noisy restaurants; this difference appears to be related to the compression and multiband characteristics of the hearing aids tested. In the 57-patient group study, many subjects showed drops in aided performance when the signal-to-noise ratio remained at -10, but the loudness levels increased by 10 dBA. Aided performance at higher noise levels was sometimes improved by changes in the compression settings or ear-mold configuration.

Recommendations

Ear examinations, including audiologic tests, are indicated in persons who admit to or are reported to have difficulty understanding conversations in restaurants. Untreatable hearing losses, of which the most common are the sensorineural type, can be mitigated with the appropriate hearing aids.

The following suggestions will be helpful to all persons wishing to converse effectively in restaurants:

- Ask for a quiet table;
- Do not sit near the kitchen or the walls, bar, or bus or waiter stations;
- Think "soft"—that is, patronize restaurants with plush environments (rugs, wall coverings, tablecloths, plants);
- Avoid restaurants providing live or recorded music;
- Avoid crowded places, especially small rooms, and periods of peak occupancy.

Fitting protocols for hearing aids and evaluations of their performance should better reflect the context of hearing-aid use. Speech testing, not just pure-tone testing, is essential. Unaided and aided sound-field speech discrimination tests in both quiet and noise should be used routinely in selecting and dispensing hearing aids to verify their appropriateness and effectiveness. Because the spectral characteristics of noise vary, hearing-aid performance should be evaluated using compact disc recordings of the environments in which a person routinely functions.

Binaural behind-the-ear hearing aids that are nonlinear, adaptive, and are equipped with multiband compression circuitry and soft, deep, nonoccluding or maximally vented continuous flow amplification ear molds are currently the hearing-aid system of choice for patients with high-frequency sensorineural hearing losses who need to understand speech, not just in quiet, but also in noise.

Equivalent hearing aid performance in noise cannot be expected for all patients with any given hearing aid technology. Patient expectations must be realistic; counseling by a physician and the support of family members are essential. Judgments of any improvements in speech discrimination must be relative to the medical and audiologic nature of the hearing loss as well as the age, lifestyle, motivation, and cognitive capacity of the patient.

The hearing aid industry, driven by intrinsic economics rather than social responsibility, is generally not (despite advertising claims) marketing hearing aids that incorporate the more important currently available technologic advances. Because physicians must assume ultimate responsibility for maximizing the benefits of hearing aids provided for their patients, it is incumbent on them to be aware of and demand state-of-the-art technology from the hearing aid industry and optimal evaluation, fitting, and follow-up services by audiologists and dispensers. The hearing aid industry should be urged to tailor compression spectra to real-world environments (perhaps to the restaurant noise models) and to develop both internal electronic adaptability and user-controllable variability in compression features. Until the major limitations and defects of the linear in-the-ear configuration can be eliminated, the industry would better serve the public by improving, promoting, and creating demand for high-technology behind-the-ear aids.

REFERENCES

1. Maurer JF, Rupt RR: Hearing and Aging: Tactics for Intervention. New York, NY, Grune & Stratton, 1979
2. Working Group on Speech Understanding and Aging (CHABA): Speech understanding and aging. J Acoust Soc Am 1988; [vol 3]:859-893
3. Mosher ER, Jelonek SJ: Real Ear Measurement of Noise and Aided Performance in Noise. Presented at the American Speech, Hearing, and Language Association meeting, November 1991
4. FDA Med Bull 1993; 23:8
5. Gardner H: Auditory training in high frequency hearing loss. Hear Instrum 1985; 35:26-28
6. Gardner H: High frequency consonant word lists. Hear Instrum 1987; 38:28-29
7. Licklider JCR, Miller GA: The perception of speech, *In* Stevens SS (Ed): Handbook of Experimental Psychology. New York, NY, J Wiley, 1951, pp 1040-1074

8. Frye GJ: The crest factor and composite signal for hearing aid testing. Hearing J 1987; 40:15-18

9. Zagat Restaurant Surveys. New York, NY, Zagat Survey, 1992

10. Staab W: Hearing Aids, A User's Guide. [Self-published: 512 E Canterbury Dr, Phoenix, AZ 85022] 1991

11. Teder H: Noise and speech levels in noisy environments. Hear Instrum 1991; 41:32-38

12. Kochin S: Why 20 million in US don't use hearing aids for their hearing losses. Hearing J 1993; 46:26-31

13. Kochin S: One more time . . . What did the 1984 HIA survey say? Hear Instrum 1990; 41:10-20

14. Yanick P, Drucker H: Signal Processing to Improve Intelligibility in the Presence of Noise for Persons with a Ski-Slope Hearing Impairment. IEEE Trans Acoustics, Speech and Signal Processing, ASSP-24, 1976, pp 507-512